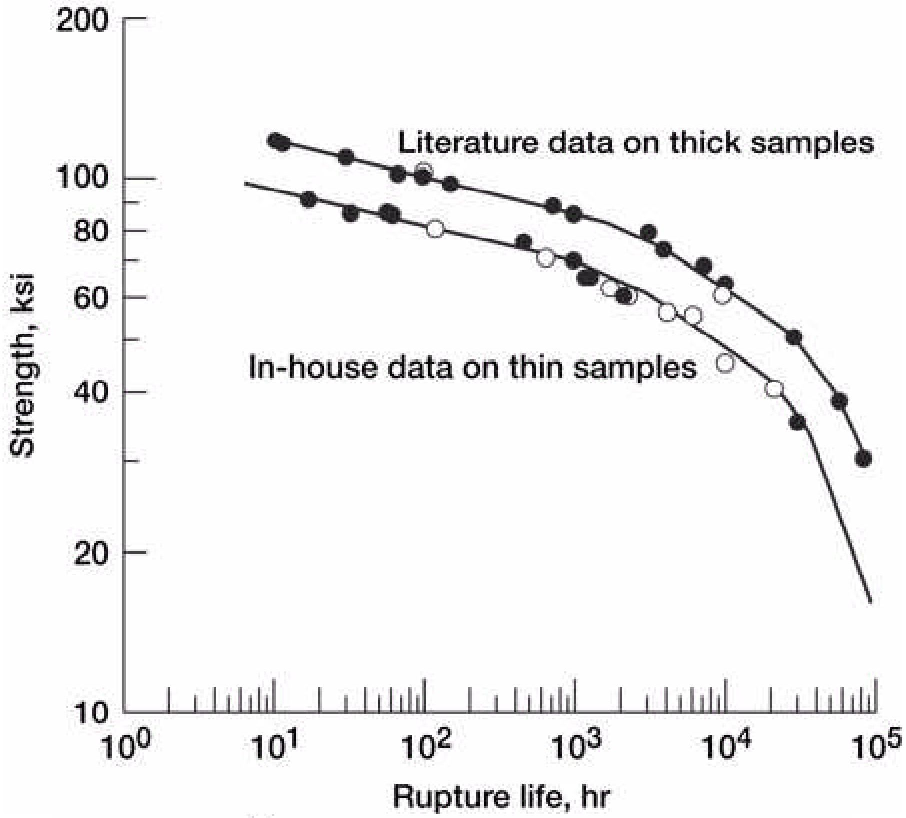
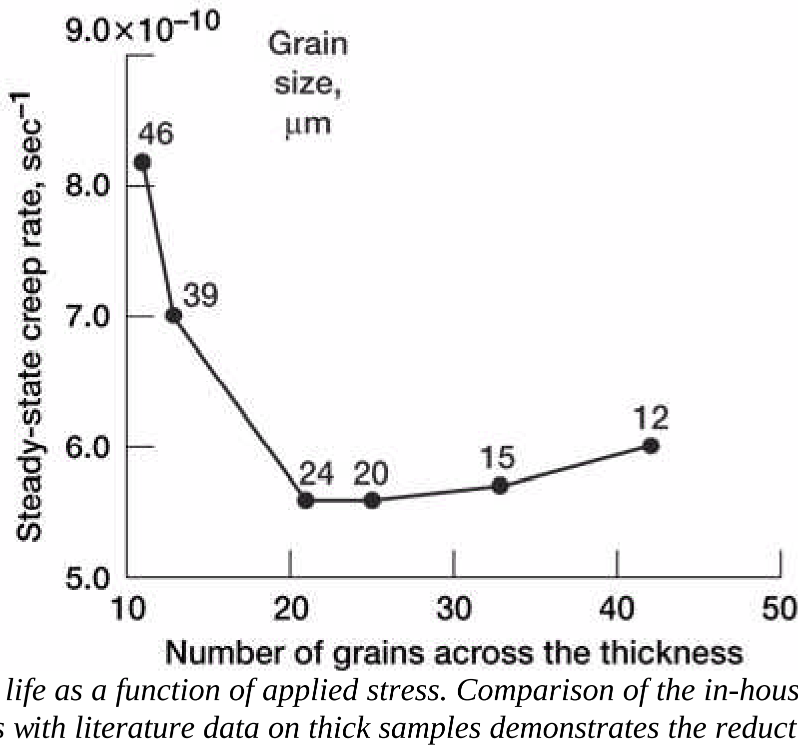
Long-Term Creep of a Thin-Walled Inconel 718 Stirling Power-Convertor Heater Head Assessed

The Department of Energy and NASA have identified Stirling power convertors as candidate power supply systems for long-duration, deep-space science missions. A key element for qualifying the flight hardware is a long-term durability assessment for critical hot section components of the power convertor. One such critical component is the power convertor heater head. The heater head is a high-temperature pressure vessel that transfers heat to the working gas medium of the convertor, which is typically helium. An efficient heater head design is the result of balancing the divergent requirements of thin walls for increased heat transfer versus thick walls to lower the wall stresses and thus improve creep resistance and durability. In the current design, the heater head is fabricated from the Ni-base superalloy Inconel 718 (IN 718, Inco Alloys International, Inc., Huntington, WV).

Although IN 718 is a mature alloy system (patented in 1962), there is little long-term (>50,000-hr) creep data available for thin-specimen geometries. Since thin-section properties tend to be inferior to thicker samples, it is necessary to generate creep data using specimens with the same geometry as the actual flight hardware. Therefore, one facet of the overall durability assessment program involves generating relatively short-term creep data using thin specimens at the design temperature of 649 °C (1200 °F).





*Left: Rupture life as a function of applied stress. Comparison of the in-house data of thin specimens with literature data on thick samples demonstrates the reduction of life associated with a smaller thickness. Right: Steady-state creep rate of thin (0.05-cm-thick) IN 718 specimens as a function of grain size. Specimens tested at 649 °C with an applied stress of 414 MPa. Grain sizes are shown in parentheses. Minimum creep rate is achieved with 24-*mm *grains.*

Long description

Right: Relationship between the applied stress and the resulting rupture life for Inconel 718. One set of data shows the relationship for data taken from the literature that was measured on thick samples. The other curve, which was generated at NASA Glenn using thin samples, shows that for a given stress, the resulting rupture life is significantly lower.

Left: Creep rate of thin specimens of Inconel 718 measured at 649 °C with an applied stress of 414 MPa versus the grain size of the particular specimen. A minimum is observed at a grain size of 24 mm, which corresponds to about 20 grains through the thickness of the specimen.

On the basis of more than 63,000 hr of cumulative creep testing, combined with metallurgical analysis, materials research at the NASA Glenn Research Center has resulted in a heat treatment and microstructure that optimizes the creep behavior of thin sheets of the nickel-base superalloy IN 718. For instance, creep testing of thin samples with various grain sizes provided data that allowed a determination of the ideal grain size for this application. The ideal size was determined by balancing the opposing needs of, on the one hand, having large grains so as to maximize creep life while, on the other hand, avoiding the mechanical property debit associated with large grains, which arises when there are too few grains through the wall thickness.

The overall life-prediction methodology consists of generating a material-specific database for the Stirling power convertor application, defining the appropriate definition of failure, developing a probabilistic design methodology, and verifying the critical flight hardware using benchmark tests. For the final validation of the flight hardware design, the life models will be calibrated and verified with benchmark tests on actual heater heads under prototypical operating conditions.

Creep life predictions based on existing literature data combined with in-house test results of the actual flight hardware material indicate that heat treatment and microstructural optimization efforts increase expected life from approximately 60,000 to near 80,000 hr. Unfortunately, given the present operating conditions, even the optimized material will not achieve the goal of 100,000-hr life. On the basis of the results of the material analysis, modifications to the heater head geometry have been suggested that would allow the optimized material to achieve the desired mission life.

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